

1 THE USGS MODULAR MODELING SYSTEM MODEL OF THE UPPER COSUMNES RIVER

1.1 Introduction

The Hydrologic Model of the Upper Cosumnes River Basin (HMCRB) under the USGS Modular Modeling System (MMS) uses a modified Precipitation-Runoff Modeling System (PRMS) to simulate daily stream flows when precipitation and temperature values are given. This model is referred to as MMS-HMCRB hereafter in the report. The MMS-HMCRB is capable of simulating hydrologic state variables which describe the hydrologic conditions of the Cosumnes River basin in time and lumped space, i.e., flood peak discharges, fall low flows, snow accumulation, soil moisture storage, water storage in ground reservoir, etc. The model may be used to study the hydrologic conditions in Cosumnes River basin under different water use scenarios (e.g., with diversions and without diversions). During the course of this project, we restructured the existing Watershed Hydrologic Model for the Cosumnes River basin (the modified MMS PRMS) so that hydrographs can be obtained at points that coincide with the water quality sampling points in the watershed. Re-calibration of model parameters for the reconstructed model has also been carried out. Hydrographs were generated with the modified MMS PRMS model for the Cosumnes basin for the period October 1998 through February 2002 for 19 subbasin outlets in the upper watershed, which coincide with where the water quality group is collecting data. The hydrographs were then provided to the water quality group for their studies. Details of this portion of the project are presented in the next sections.

1.2 Model Setup

MMS-HMCRB was developed to be run in Linux-based computers. It uses X-windows and Motif for its graphical user interface (GUI). The main graphics window of MMS-HMCRB is shown in Figure 1.1. Editing of model parameters, model calibration and simulation runs can be done interactively under the GUI of the model. MMS-HMCRB also has a geographic information system (GIS) interface which is capable of displaying the spatial distribution of model parameters and of the spatial and temporal variation of simulated state variables during a model run.

The Cosumnes River Basin was divided into 39 subbasins and 83 hydrologic response units (HRUs) in the original MMS-HMCRB model. In the modified MMS-HMCRB model to accommodate the water quality sampling team, the Cosumnes River Basin was divided into 32 HRUS that make up 19 subbasins whose outlets coincide with the sampling points in the upper basin. The outlet of the upper basin is located at Michigan Bar.

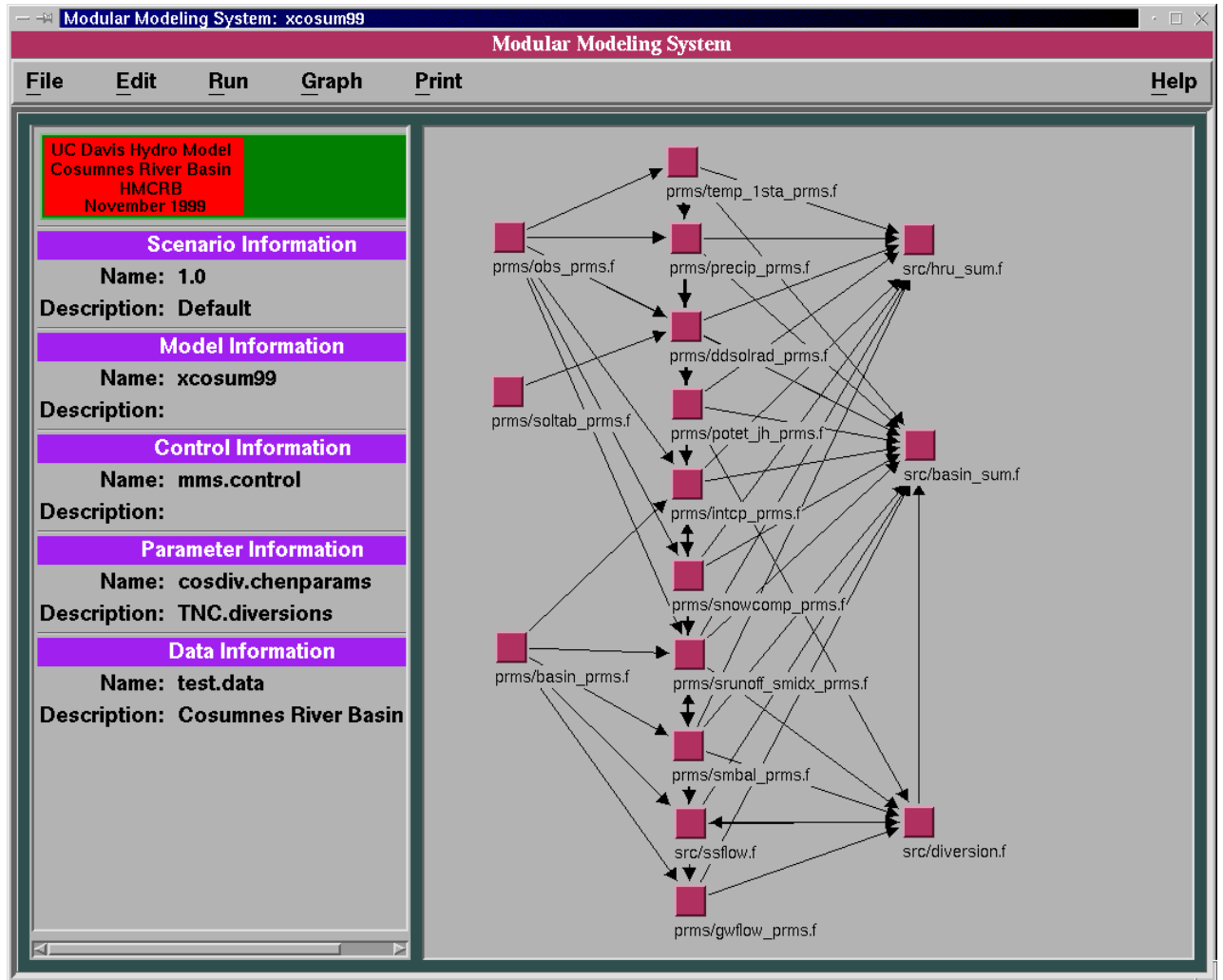


Figure 1.1 Graphical User Interfaces of HMCRB. The flow chart in the middle shows the modules used in the HMCRB and the data flow between modules.

HRUs are the basic computational elements in MMS-HMCRB. MMS-HMCRB uses water storage terms in order to control the water flow between different flow processes in the basin. The seven types of storage in the model as well as the flows in between them, as shown in Figure 1.2, are described as follows.

Interception storage contains precipitation that is held on vegetation leaves in the basin. Interception capacity is a function of seasonal vegetation cover density in the model. Precipitation (rain, snow, or a mixture of both) falling on a HRU was determined using its elevation, the daily precipitation observed at a climate station nearby and the daily maximum and minimum air temperatures from the same station or another climatic station.

Snowpack storage represents the snow accumulation on land surface. Snowmelt from the snowpack of a HRU was determined by observed daily maximum and minimum air temperatures and the solar radiation computed using potential solar radiation and the slope/aspect values of the HRU. The evapotranspiration computation also uses the solar radiation term.

Impervious zone storage contains water on the impervious land surface such as roads. When impervious zone storage reaches its capacity, surface runoff occurs in the model. Surface runoff was modeled as a function of antecedent soil moisture and rainfall amounts.

Soil zone storage holds water in the root zone. Infiltration, depletion, and recharge to the soil zone storage, to the subsurface storage, and to groundwater storage were related to the soil zone storage.

Subsurface storage contains water between the root zone and groundwater table and is available for relatively rapid movement to streams in the basin. The groundwater storage is the water which generates all stream base flow. Subsurface flow occurs during, and for a period, after rainfall and snowmelt. It moves faster than groundwater. Both subsurface flow and groundwater flow were modeled by non-linear storage routing schemes. The groundwater storage routing scheme regulates how much water from groundwater storage goes to stream reach and how much water goes to groundwater sink.

The diversion stock pond storage is the water that was stored in the stock pond before being applied to the field. Diversions were modeled using water right data and the evapotranspiration loss from irrigated lands and storage ponds.

No channel routing is performed with the daily time step in the model, which is equivalent to assuming that the changes in stream storage of all reaches are zero at the daily time increment.

System inputs to MMS-HMCRB are the daily precipitation and daily maximum air temperature, and daily minimum air temperature, as shown in Figure 1.2. The original MMS-PRMS allows snow accumulation and solar radiation as its system inputs, but such data sets are not available in Cosumnes River Basin. The diversion data were treated as parameters of the basin, and do not vary from time to time. Therefore, they do not appear in the input file of the model. The input file of MMS-HMCRB contains observed stream flow for calibration purposes.

The major water outputs from the basin are the stream flow at the basin outlet and the evapotranspiration terms from various storages, which are shown as “ET” clouds in Figure 1.2. An ET term may consist of evaporation, transpiration, and/or sublimation. Groundwater sink and water exports are also accounted for as water outputs from the basin in order to balance the water quantity in the basin.

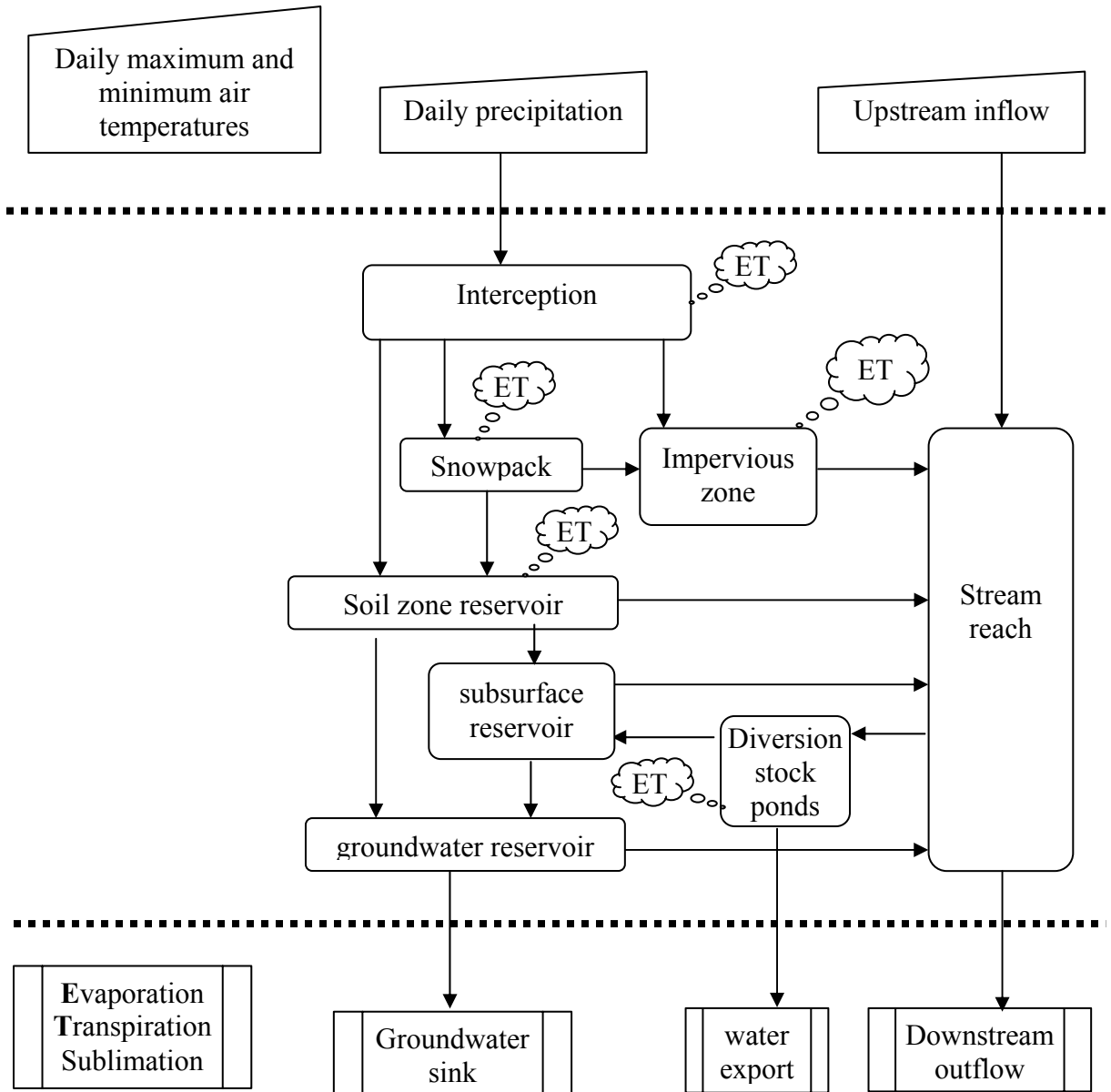


Figure 1.2 A diagram showing all input, output and storage terms accounted for by the MMS-HMCRB. The top part shows the inputs, the middle part shows the storage terms, and the lower part shows the outflows.

1.3 Model Calibration

Since MMS-HMCRB is a conceptual lumped hydrologic model, most of the model parameters need to be determined by calibration. Calibration is a process of varying the coefficients (parameters) of the model in order to make the simulated daily flow hydrographs match the observed hydrographs in the basin. Calibration and evaluation of MMS-HMCRB were done as follows.

- 1) selecting stream gage stations in the basin and delineating the basin into HRUs and subbasins;
- 2) selecting hydrometeorological observation stations in the basin and associating each HRU to a hydrometeorological observation station;
- 3) determining the default model parameters using available information such as DEM, soil data and vegetation data.
- 4) identifying hydrologic processes that have significant effects on the stream flow and identifying the parameters of the hydrologic processes that have most influence on the stream flow;
- 5) adjusting the identified model parameters and making the simulated daily flow hydrographs match the observed hydrographs as closely as possible;
- 6) verifying the model by simulating water conditions in a selected historical time period during which observed precipitation data, observed air temperature data and observed stream flow data were available in the basin.

The actual calibration procedure for a particular hydrologic basin depends on what types of observation data are available in the basin. MMS-HMCRB has been calibrated by historical climatic data (daily precipitation and daily maximum and minimum temperatures), historical stream flow data and the diversion data. Historical stream flow data from six stream gage stations in the Cosumnes River basin and historical climate data at nine climate observation stations around the Cosumnes River basin, as shown in Figure 1.3, are available for various time periods within the last 90 years.

The historical stream discharge data at the gage station of North Fork Cosumnes River near El Dorado and at the gage of South Fork Cosumnes River near River Pines were used in the parameter calibration for the HRUs upstream of the corresponding gage stations, respectively. The other two stream gage stations that are currently operational in Cosumnes River basin are Camp Creek near Somerset and Michigan Bar gage stations. Both of them have stream discharge records available. The Michigan Bar gage station has the most complete stream discharge record in the basin. The model evaluation in this report was based on observed stream discharges at Michigan Bar and was done for the subbasins that are located upstream of Michigan Bar gage station, as shown in Figure 1.4. The Michigan Bar stream gage is located at the outlet of subbasin #6.

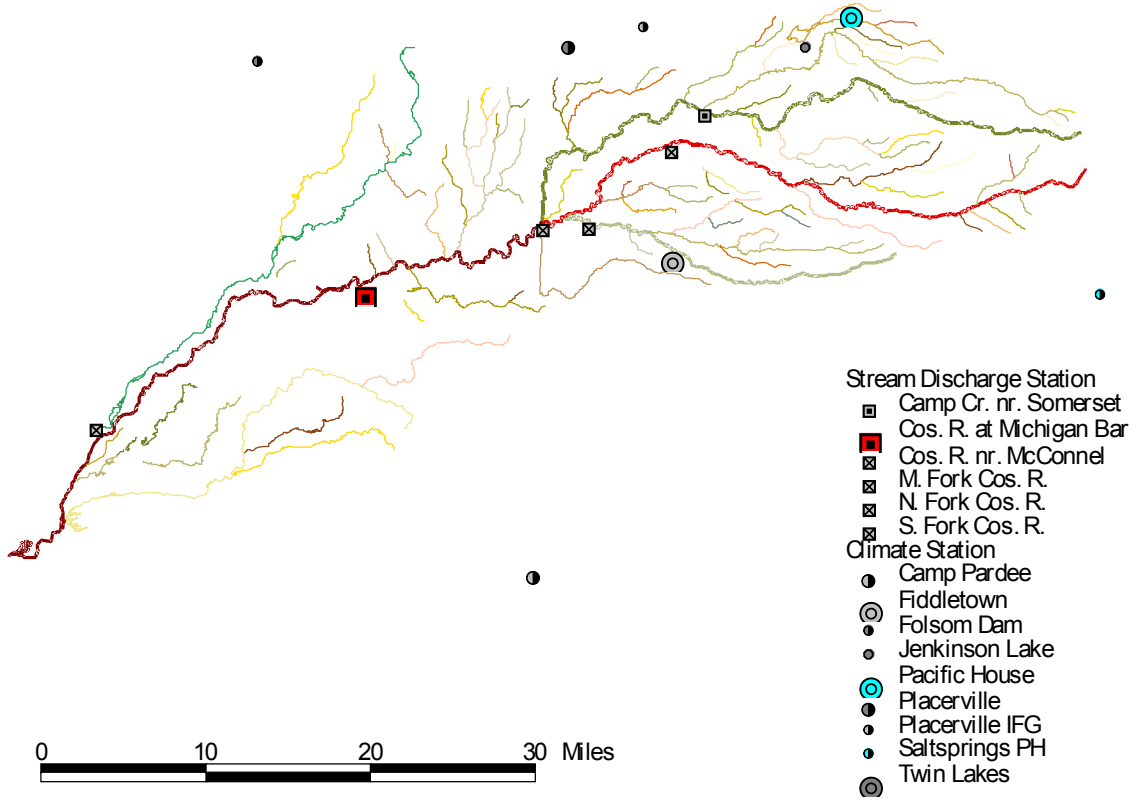


Figure 1.3 The stream discharge and climate observation stations in Cosumnes River region.

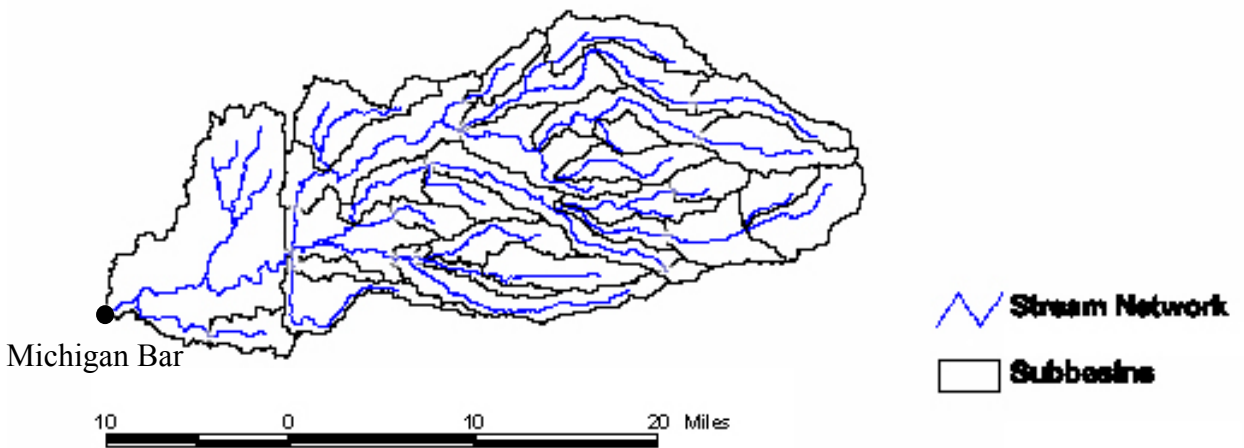


Figure 1.4 Subbasins and stream network of Cosumnes River basin upstream of Michigan Bar.

Diversion data must be incorporated into the model as fixed model parameters before calibration. The diversion data was developed from the water rights permit data in the State Water Resources Control Board (SWRCB) of California and topographic maps. In order to quantify the flow process caused by diversions, MMS-HMCRB uses the following information: diversion limit, diversion's source HRU, area of a diversion pond, volume of a diversion pond, diversion pond's HRU, diversion's on-day in a year, diversion's off-day in a year, and the date when the water right was granted for a diversion. Figure 1.5 shows the spatial distribution of diversion limits in Cosumnes River basin upstream of Michigan Bar.

The hydrometeorological stations that have daily precipitation and air temperature observations inside the basin and/or near the basin boundary were then assigned to each HRU of the model. This assignment determines how much precipitation each HRU will receive and what maximum and minimum daily air temperature the HRU will have. The most important parameters in the MMS-HMCRB that control the water balance of the model are the precipitation adjusting factors and the coefficients of the evapotranspiration process. The precipitation adjusting factors represent the differences between the observed precipitation amount and the received precipitation amount by each HRU in the model. These parameters are the controlling parameters for the water balance in the model. The parameters for snowmelt processes in the upper basin have effects on the stream flow not only in the winter snow season, but also in the spring and summer because there may exist snow cover in the upper Cosumnes River basin even in June of the year. The coefficients of the nonlinear subsurface reservoirs and the linear groundwater reservoirs have significant impacts on the recession part of the hydrograph that is simulated by the model. The graphical user interface of MMS-HMCRB makes the task of adjusting the parameters in the model very easy, but we need to know what to adjust since there are thousands of parameters in the model which can be adjusted.

Some of the parameters in MMS-HMCRB can be estimated roughly using the digital elevation data, soil type map, land use and land cover maps, and vegetation map, which contain the basic geographic and physical information of the basin. Using the soil and forest data in STATSGO data set of California, we have generated a data set that describes the physical properties of the land surface in the Cosumnes River basin. This data set includes the spatial distributions of the soil depth from surface to bedrock or impermeable soil layer, soil porosity, soil hydraulic conductivity, standard deviation of the log of soil hydraulic conductivity, and forest cover. Some of the data in this data set may not be useful for MMS-HMCRB, such as the soil hydraulic conductivity and its standard deviation, but they will be used with a physically-based watershed model under development for the upper Cosumnes River basin, as described in Chapter 2 of this report.

Diversions in Upper Cosumnes River Basin

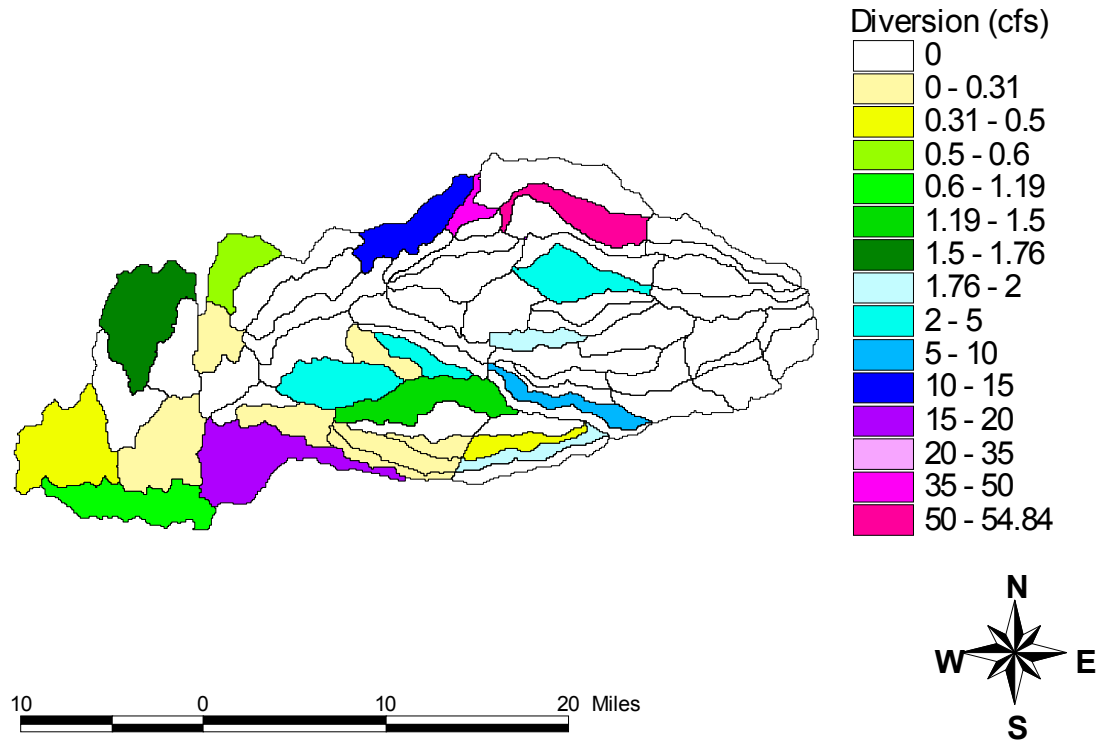


Figure 1.5 Spatial distribution of diversion limits in Upper Cosumnes River Basin. The values in the figure represent the sum of diversion limits in a HRU.

1.4 Simulation Results and Discussions

After calibration, simulations were run for the time period September 1998 to February 2002 in order to provide flow data to the water quality sampling group at their sampling sites in the upper basin. Simulation results with and without diversions were provided to the water quality group. A sample of the daily flow values provided to the water quality group is shown in Figure 1.6.

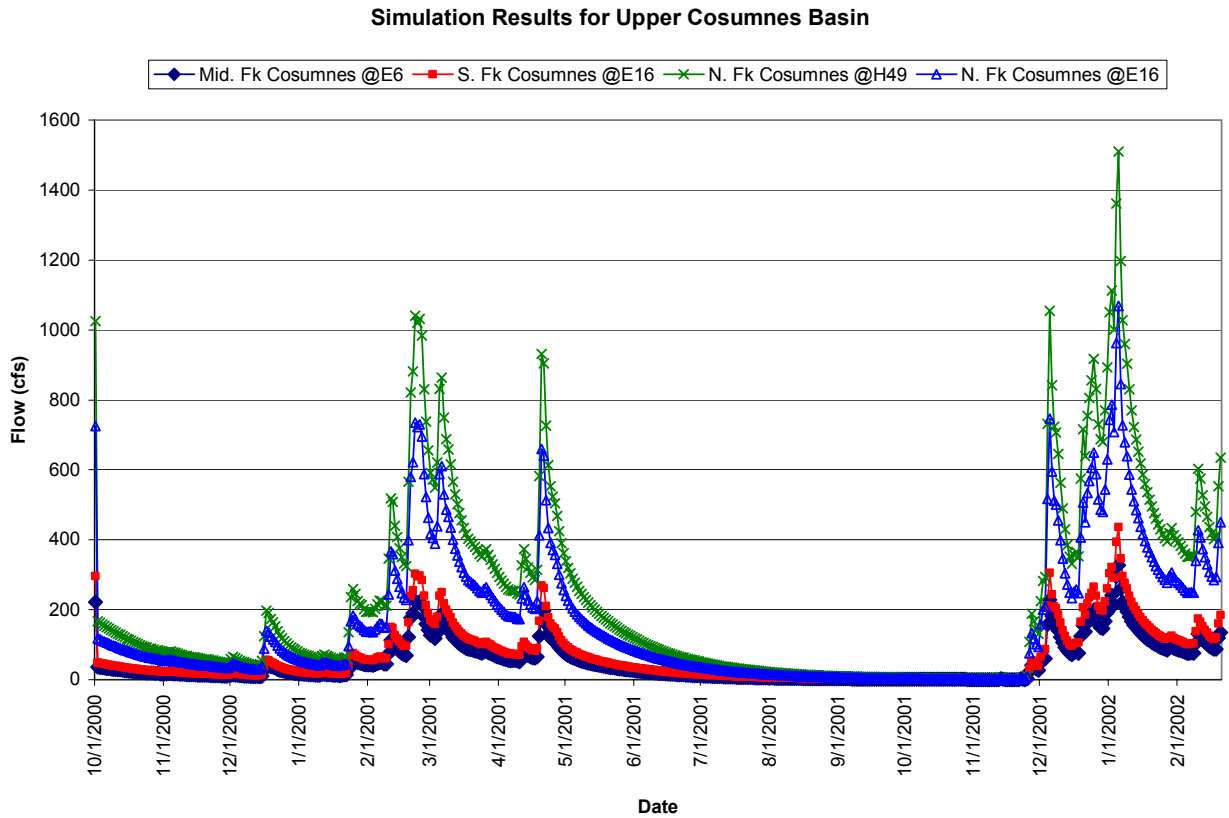


Figure 1.6 Sample simulation results from MMS-HWCRB for subset of 1998-2002 simulations carried out for water quality group.

In order to examine the performance of MMS-HWCRB with the calibrated parameter set, we have simulated stream discharges at Michigan Bar from 1984 to 1997 under two scenarios, i.e. with diversion and without diversion. This time period contains both significant flood events and the prolonged drought of 1987-1994. The full-scale hydrographs in Figure 1.7, which were generated by the simulation, show the daily mean discharges in the range of 0 to 60,000 cfs from 1984 to 1997. The 3 plots in Figure 1.7 show the hydrographs during 1984 to 1989, hydrographs from 1989 to 1994, and hydrographs from 1994 to 1997, respectively. The two big flood events of 1986 and 1997 are clearly shown in Figure 1.7. The long lasting drought from 1987 to 1992 is also shown clearly in both Figure 1.7 and in more detail in Figure 1.8.

In order to identify the low flow conditions, only the discharges in the range of 0 to 200 cfs were plotted in Figure 1.8. The observed discharges in the figure indicate that the Cosumnes River dried out (zero-cfs-flow at Michigan Bar) during summer and/or fall in the seven drought years. It can be seen in Figure 1.8 that the model did not make a reasonable prediction of low flow conditions when comparing the observed discharges with the simulated discharges in low flow periods. For example, the observed discharges show that Cosumnes River dried out only in 7

drought years, but the model predicts that Cosumnes River has dried out in summer or fall almost every year during the 14-year period, as shown in Figure 1.8.

The discharges simulated with diversion and the discharges simulated without diversion are almost identical in the low flow periods, as shown in Figure 1.8. This shows that diversions do not have significant impact on the model prediction of the fall low flow in upper Cosumnes River basin. From the results obtained under the two scenarios, we may conclude that legal diversions in the upper Cosumnes River do not have obvious effects on low flow conditions in Michigan Bar. Such a conclusion is questionable. There is either no water in the stream for diversion, or the diversion is not allowed in low flow periods. The diversion data shows that most of the diversions are allowed in winter or spring but not in summer or early fall. By removing the few big water diversions in upper Cosumnes River, which were shown as red and purple coverages near the Jenkinson Lake and the South Fork of Cosumnes River in Figure 1.5, the total diversion amounts in upper Cosumnes River can be reduced significantly and the rest of the diversions in the upper Cosumnes may only have minimal impact on the low flow conditions at Michigan Bar.

The diversion model in MMS-HMCRB assumes that people will divert the maximum amount of water that is legally allowed because we do not have the actual diversion data available. The model mistakenly predicts dried-out conditions at Michigan Bar in wet years such as 1995 and 1996 because of the above assumption, as shown in Figure 1.8. This unrealistic assumption makes model calibration very difficult. The explicit diversion model with unrealistic diversion data does not produce good predictions. Water may be released from Jenkinson Lake in the summer or fall, but there is no reservoir operation module in MMS-HMCRB. A more realistic approach should incorporate the water demands by crop and vegetation into the model. More field investigations are needed in order to identify the consumptive use and evapotranspiration patterns in the basin.

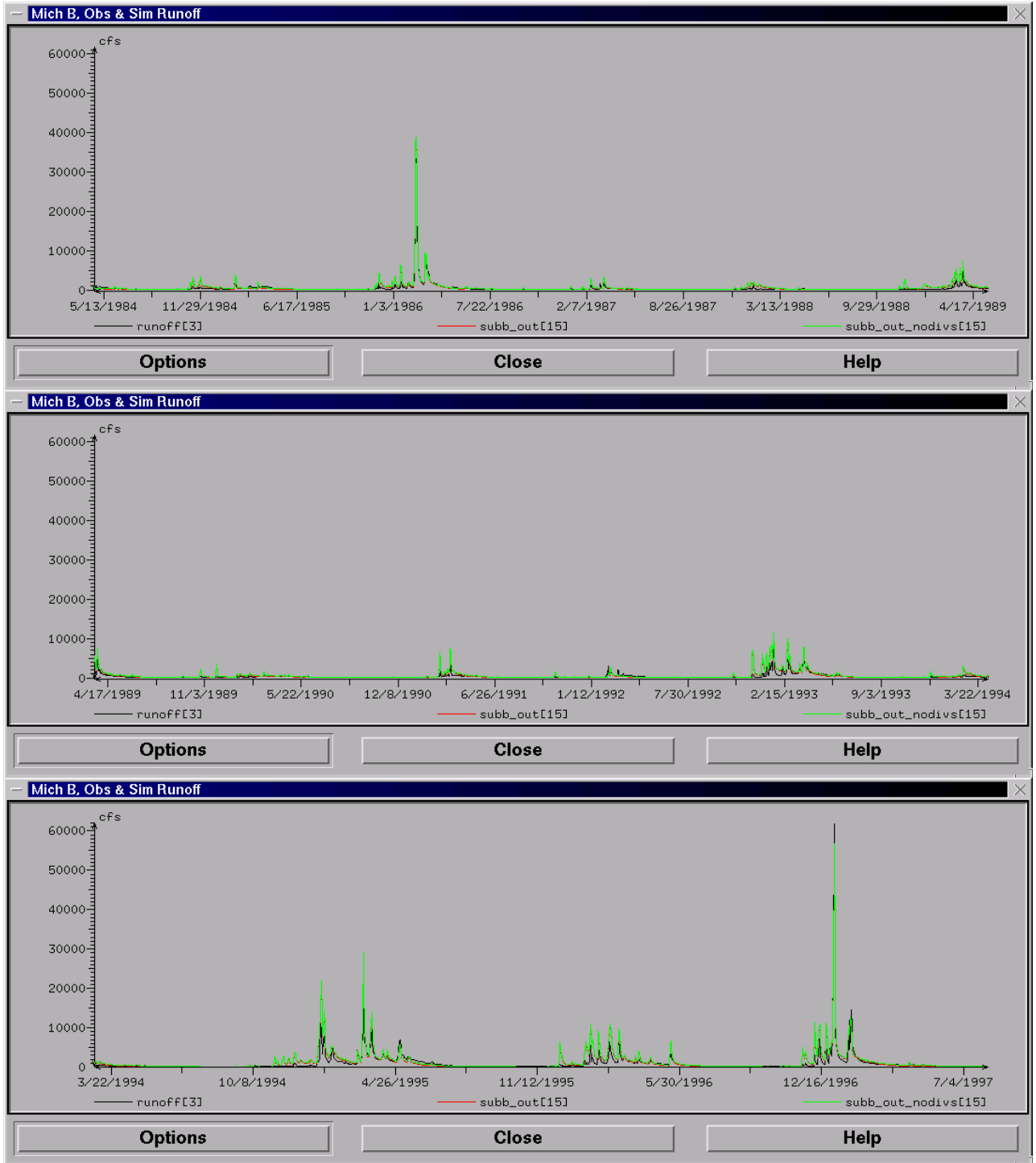


Figure 1.7 Comparison of observed stream flow (black line), simulated stream flow with diversion (red line), and simulated stream flow without diversion (green line) at Michigan Bar from 1984-1997.

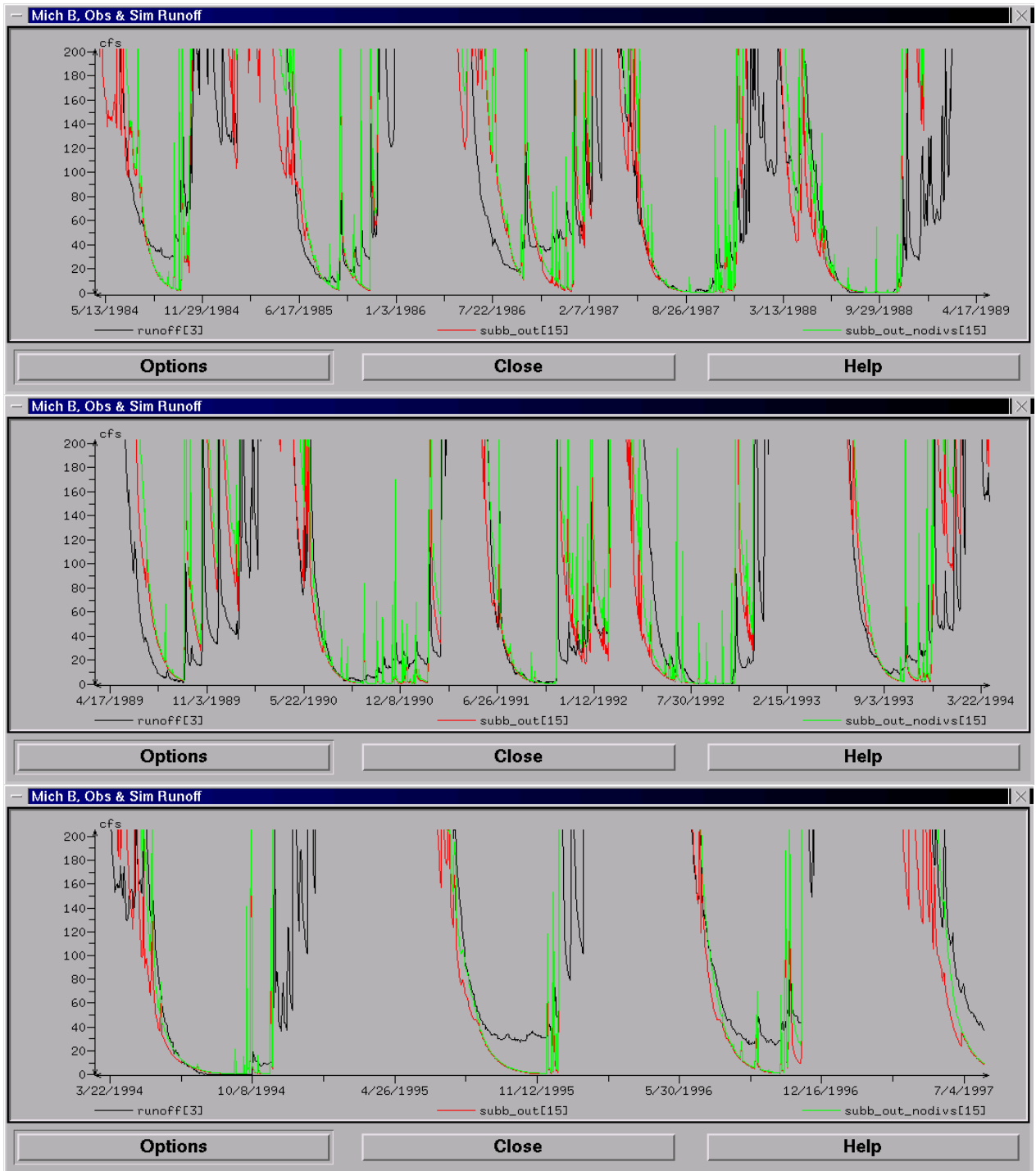


Figure 1.8 Comparison of observed stream flow (black line), simulated stream flow with diversion (red line), and simulated stream flow without diversion (green line) at Michigan Bar from 1984-1997 in the low flow range of 0-200 cfs.

The fall low flows in Cosumnes River are affected by the soil moisture storage accumulated in winter and spring in the basin and by the evapotranspiration during spring and summer. The timing of the snowmelt at the upper basin has a significant effect on floods and fall low flows. Accurate distributions of precipitation and temperature in the basin are two of the determining factors for the success of the flood flow and fall low flow simulations. Good temperature measurements are currently available at only two of the nine climate stations shown in Figure 1.2. Spatial distribution of air temperatures determines the spatial distribution of precipitation type in the model. It also controls the snowmelt process in the model. Just two temperature observation stations can not provide sufficient information to quantify the spatial distribution of air temperature in the basin. Simulation results have shown that further improvement in precipitation and temperature inputs to MMS-HMCRB are required. Successful simulations for both flood peak flow and fall low flow depends on the precipitation and temperature distributions. Therefore, it would be beneficial to add more hydrometeorological observation stations into the basin, or to utilize numerical meteorological models to provide the model with more consistent hydrometeorological input data.

Relating geological, physical, and biological characteristics of the Cosumnes River basin to the parameters of a hydrologic model is essential for assessing the hydrological impacts of land use and water management scenarios in a basin like Cosumnes River basin. It is very difficult to do such work with MMS-HWCRB since the most important parameters of the model were determined by calibration. Because of these issues, it was decided to start the development of a physically based watershed hydrologic model of the Cosumnes. With such a model, it will be much easier to simulate the hydrologic conditions under different management scenarios because the model parameters can be related directly to physical, geological, and biological attributes of a watershed. Efforts in the development of this physically based watershed hydrologic model of the Cosumnes River Basin is described in Chapter 2 of this report.